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Instructions for Using the 250 cm² Shear Frame to Evaluate the Strength of a Buried Snow Surface

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Proper use of the shear frame following the instructions presented here will give accurate measurements of the strength of a weak surface within the snowpack. The method requires the use of the 250 cm² shear frame. It also requires a minimum of 21 measurements on each surface and a calculation that estimates the large-surface strength from the small-surface tests.

Keywords: Snow, avalanches, strength, mechanical properties

Introduction

Research on dry slab avalanches has shown that a bed surface failure must occur before the tensile stress increases sufficiently to cause the release of a slab avalanche. Furthermore, it has been shown that when statistical fracture theories are applied to small shear frame tests, the strengths measured on the sliding surfaces of avalanches show very good agreement with the loads on those surfaces. These results indicate that shear frame tests could be used to predict the load-bearing capacity of potential avalanche sliding surfaces. If such a technique could be made operational, it would provide more objective data for use in avalanche prediction.

No field method is now being used to accurately predict the stability level of a particular slope. Even when it is known that there is an unstable layer or surface that is widespread throughout an area, the severity of that instability cannot be measured. Currently, the major techniques for the study of snow properties are the snowpit and the shovel shear test. Their main application is in the evaluation of the strengths of thin, weak layers and of the strengths of surfaces between layers. However, the techniques that are used can only give a qualitative evaluation of the strength. Although this is valuable, it cannot be recorded in such a way that it can be transmitted to other people or retained for future reference. What is really needed is a way to measure these strengths so that they may be recorded and so that they have the same meaning to all people.

In the past, there have been attempts to attach numbers to measurements made in the snow, and to correlate those numbers with stability. Although the most widely used of these, the ramsonde index, gives some information on the strength of snow, the information is not complete enough to be reliable in the estimation of snow stability. The major shortcoming is the fact that the index cannot measure the strength of thin layers and surfaces between layers.

The shear frame test is currently in use to a limited extent, giving qualitative evaluations, but the techniques are questionable. The method described below is an attempt to standardize the technique so it is scientifically acceptable.

To understand the importance of thin layers and surfaces, it is necessary to understand the role of shear failure in avalanche release. It has long been known that a tensile fracture forms the crown of slab avalanches. Research in the last ten years has shown that it is not possible to have enough tensile stress at the crown to break snow without first having a shear failure on the sliding surface (Perla and LaChapelle 1970, Curtis and Smith 1974). The situation is like a climber standing on a slope on belay but without direct aid. He won't pull on the belay rope unless his feet slip out from under him. In the same way, snow can generally stand on a slope, even

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without tensile support. However, if the "feet" of the snow layer slip out, then it needs the tensile support to stay in place. The problem of finding a measurement technique becomes the problem of measuring the strength of the surface that will become the sliding surface if the slope goes unstable.

The 250 cm² Shear Frame

Research has shown that the shear frame (fig. 1) can measure the shear strength of the sliding surfaces of avalanches after release (Sommerfeld et al. 1976, Perla 1977, Sommerfeld and King 1979, Perla 1982). The reasons that the values obtained agree so well with the expected values are still the subject of debate among researchers. However, this agreement brings up the possibility that the technique could be used for the prediction of the stability of individual slopes. It is easy to calculate the shear load on a suspected sliding layer and to calculate the additional load from a predicted storm if the precipitation prediction is accurate (Perla and Martinelli 1976). By using standard methods to compensate for the high variability in the measurements, the strength of known sliding surfaces can be calculated with very good accuracy from shear frame measurements. The big question then is: Can this type of measurement be used to predict avalanches? This question breaks down to two questions: Where should we make the measurement and when should we make them? The answer to the first question is: As close as practical to the point where the avalanche is expected to release. What little information is available indicates that usually you have to make the measurement on the right surface and in the starting zone, but not necessarily on the exact starting spot. As for time, current information indicates that the results are only good for about 24 hours. However, there really is not enough information yet to have any confidence in these answers. Research projects are now being carried out to provide the needed information, but part of the answer must come from field trials of the technique.

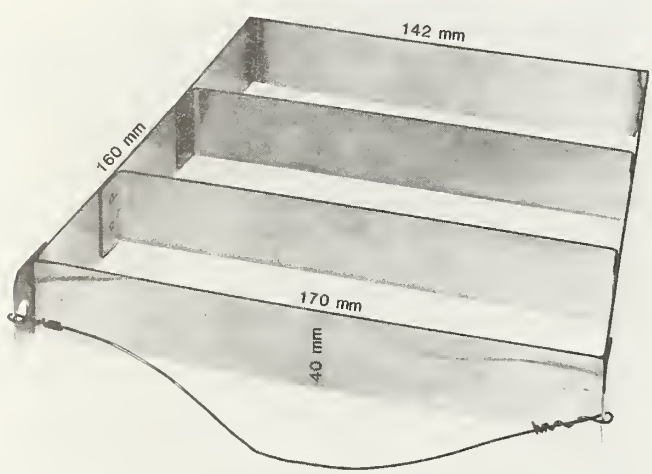

Figure 1—Shear frame with a base area of 250 cm².

The main dificulties with this test arise because (1) the surfaces to be tested are in the body of the snow, and (2) the size instruments that are practical to use give extremely variable measurements of snow strength. The first fact means that the measurements must be done in a snowpit, and the second that many measurements must be made on each potential sliding surface. This variability is the most annoying aspect of snow research, but it can't be ignored. Taking only one measurement of the shear strength of a surface is like finding the average height of Americans by measuring the height of the first person you meet. So, with the 250 cm² shear frame, 20 to 25 measurements must be taken; with the 100 cm² frame, at least 51 measurements are necessary. Therefore, we recommend the larger frame. Frames larger than 250 cm² are not practical to use (Perla 1977). Basic snowpit technique is well covered in the "Avalanche Handbook" (Perla and Martinelli 1976).

The method outlined below must be followed exactly for the results to be accurate. In particular, it is important to use the right units and do 20 to 25 shear tests. The first five steps must be done in the field; steps 6 through 9 can be done in a more comfortable location. Each step will be covered in detail later.

1. Dig a pit and prepare the pit wall to make the layering visible, as shown in the "Avalanche Handbook" (Perla and Martinelli 1976).
2. Do a shovel test to find the potential sliding surfaces.
3. Decide which surfaces are the most important (weakest).
4. Do 20 to 25 shear tests (with the 250 cm² frame) on each important surface.
5. Measure the total thickness and average density of the snow above each surface.
6. Find the median strength (the middle value) of the measurements.
7. Find the sliding surface strength by multiplying the median by 26.
8. Calculate the shear load on the sliding surface from the overlying snow depth, density, and slope angle.
9. Subtract the shear load from the strength to find the additional load the sliding surface can stand.

A word of warning is in order at this point. This is a very experimental technique. Strict adherence will yield accurate results for the strength of the surface at the point and at the time it was measured. How this translates to the stability of the slope is still an open question. Research projects now in progress may provide part of the answer. However, field data are necessary to provide a complete answer.

Instructions for Conducting the Shear Frame Test

Digging the Pit

Dig the pit as close to the suspected crown as practical and as deep as necessary to include all important

layers. A pit near the starting zone is more representative of the conditions in the starting zone, because snow varies in different places and measurements made at one place may not be accurate for other places. After the pit is dug, smooth the uphill wall with a shovel and then brush the wall with a soft brush to bring out the layering.

The Shovel Test

The shovel test is a quick and useful way of finding potential sliding surfaces. The weak surfaces are more easily determined if a pair of vertical cuts are made in the snow wall to free the snow on each side of the shovel. These should be slightly wider than the shovel so that the snow to be tested is not restrained at the sides. To do this test, push the shovel vertically into the snow surface (fig. 2) parallel to the pit wall, about 20 cm uphill from the wall. Prying the shovel gently back and forth will make the snow fail on weak surfaces. Work down through the whole height of the pit wall with the shovel to find all the possible weak surfaces. The snow will sometimes fail in other locations, but a fairly smooth, flat failure shows a potential sliding surface (fig. 3). With experience, you can learn to estimate the surface's strength to decide whether or not it is an important source of weakness. Here, careful notetaking and recordkeeping will pay off in the long run by helping you to develop expertise and allowing you to compare measurements from different years.

Selecting the Important Surfaces

The main difficulty with this method is finding the *important* weak surfaces. Because the shear test is time-

Figure 2.—Shovel tests.

Figure 3.—Potential sliding surface.

consuming, it usually isn't possible for you to measure all the surfaces that can be found. If the layers you measure are important weak layers in the starting zone, the measurements should give you accurate and useful information on the slope stability. If you don't measure the right layers, you won't get the right numbers.

The Shear Test

Once you have decided which surfaces are important (weak), prepare the pit wall as in figure 4. Cut a bench about 20 cm wide in the pit wall. The exact width is not important but is is very important that the top of the bench exactly coincides with the sliding surface. This is best accomplished by breaking off the snow above the bench in the same way the shovel test is done. A smooth, well-formed bench will help with the next step and help get the accuracy you need.

Make a test layer by removing most of the snow from above the sliding surface, leaving a little more than the thickness of the shear frame (3–4 cm)(fig. 4). If this layer is too thin, the test will not be accurate. If it is too thick, it will be difficult to push the shear frame exactly down to the sliding layer. Expose about 2 m² in this way. Extreme care is necessary at this point to avoid compressing or disturbing the snow in the test layer in any way. Carving an accurate layer above the sliding surface is the most important part of this test. It will require practice because the sliding layer is invisible, and sometimes curves. The wider you make the bench, the easier it is to aim the shovel parallel to the bench, but the more snow you have to dig.

The bench is very important. It supports the snow below the sliding surface and insures a planar failure. Without the bench, very complicated types of fractures can happen which make the measurements unusable.

When a good bench and test layer is made, push the shear frame down through the test layer until its lower edges are just above the sliding surface. Try not to penetrate into the sliding surface. The side of the frame near you should coincide with the vertical side of the test layer (fig. 4). If there is snow in front of this side, brush it away. Next, attach the pull gage and pull with a fairly fast but smooth pull parallel to the bench. You should pull so that the sample fractures in a couple of seconds. The fracture *must* happen in less than 10 seconds. Record the force readings, move the frame, and repeat the test. At least 20 measurements are necessary for the required accuracy. It is easier to find the median if you have an odd number of measurements, so it is best to take 21 readings.

If there is more than one important weak surface, prepare each surface in turn and test it. After you have made the bench, it is better to work fast and get more data than to work very carefully and get little data.

Measuring the Density

Take density measurements as part of the standard pit measurements (see the "Avalanche Handbook," Perla and Martinelli 1976). They will be used later for load calculations. If you do not take the whole series of pit measurements, you will have to take density measurements of the layers above the sliding surfaces that are tested. You must take enough density measurements to accurately determine the average density; this means at least three measurements per layer and a measurement every 5 to 10 cm, unless the layers are unusually thick and uniform. If the complete set of pit measurements is not made, it is probably better to do the density measurements last because you can avoid making unnecessary measurements and density measurements are easier to do than shear tests when you are tired. It is recommended, however, that you do the complete set of measurements if at all possible. Careful records of crystal types, snowlayer types, etc., will pay off in the long run. They will help you to build a base of experience that will lead to better stability evaluations.

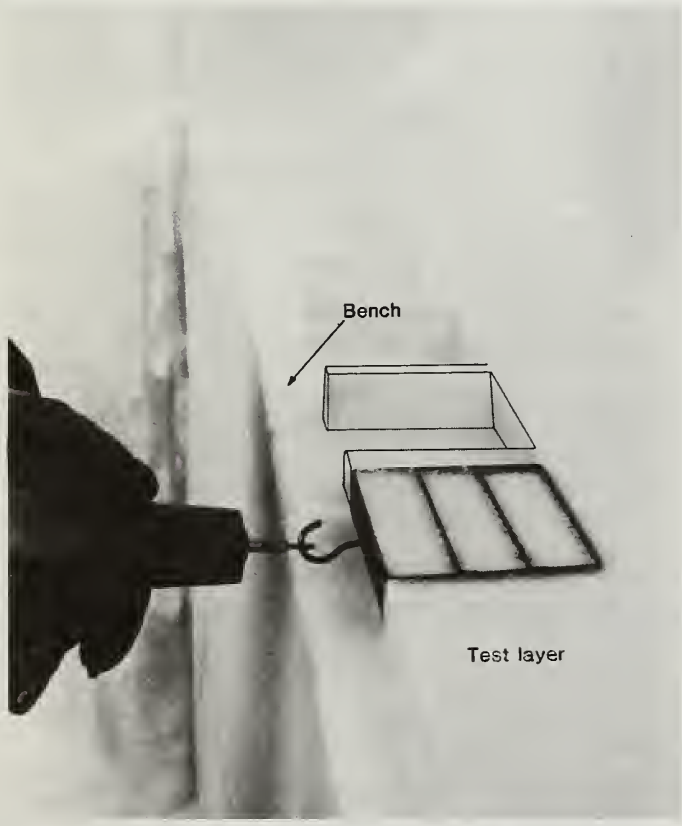

Figure 4.—Pit wall prepared for the shear test. (Source: Perla and Martinelli 1976, p. 165.)

Calculating the Sliding Surface Strength

Find the median or middle value of the measurements. You do this by placing the measurements, in order, from the largest to the smallest. You do not have to rank all the measurements, just half. If you have 21 measurements, the eleventh highest (or lowest) is the median (fig. 5A).

The area of the shear frame is one-fortieth of a square meter so you now have the median strength of the sliding surface in kilograms per one-fortieth of a square meter (fig. 5B). To get the strength per square meter, multiply by 40. Statistical studies of snow strength (Sommerfeld 1980) have shown that the true sliding surface strength is 0.65 of the median determined with this shear frame. So, multiply the median strength per square meter by 0.65 to obtain the true sliding surface strength (fig. 5C). The two multiplications can be combined in a single multiplication of 26 ($40 \times 0.65 = 26$) (fig. 5D).

Calculating the Load on the Sliding Surface

Find the average density of each layer above the sliding surface by adding the measurements in the layer and dividing by the number of measurements (fig. 5E). To get the vertical load, multiply the average density of each layer by the height of the layer (fig. 5F). Then add the results (there is only one layer in the example). To find the shear load, multiply the vertical load by the sine of the slope angle (see table 1) just below the crown of

Table 1.—Sines

Angle	Sine	Angle	Sine	Angle	Sine	Angle	Sine
20	0.342	30	0.500	40	0.643	50	0.766
21	.358	31	.515	41	.656	51	.777
22	.375	32	.530	42	.669	52	.788
23	.391	33	.545	43	.682	53	.799
24	.407	34	.559	44	.695	54	.809
25	.423	35	.574	45	.707	55	.819
26	.438	36	.588	46	.719	56	.829
27	.454	37	.602	47	.731	57	.839
28	.470	38	.616	48	.743	58	.848
29	.485	39	.629	49	.755	59	.857
						60	.866

Sliding Surface between new Snow layer and thin sun crust

	Kg f	Ranking	
1	3.10	6	
2	3.50	2	
3	3.45	3	
4	2.40		
5	2.50		A
6	3.30	4	
7	3.15	5	
8	2.90	8	
9	2.60	11	- Median
10	2.20		
11	2.25		
12	3.00	7	
13	2.90	9	
14	2.25		
15	2.35		
16	2.50		
17	2.50		
18	2.45		
19	3.65	1	
20	2.80	10	
21	2.45		

layer thickness = 33 cm

Densities (500 cm^3 samples)

GMS	Density
60	120 $kg\,m^{-3}$
57	114
61	122
70	140
68	136
5	) 632 E

Average = 126.4

Median strength = 2.60 kgf/ 1/40 m^2 B

True Surface Strength = 2.60 X 40 X .65

= 2.60 X 26 C

= 67.6 kgf/m^2 D

Vertical load = 126.4 X .33

= 41.7 kgf/m^2 F

Slope angle = 30^{o}

Sine 30^{o} = .5

Shear load = 41.7 X .5

= 20.8 kgf/m^2 G

H The slope is stable and the sliding surface can hold an additional 67.6 - 20.8

= 46.8 kgf/m^2

At a new snow density of 150 kg/m^3, this would be an additional 46.8 / .5 X150 I

= .62 meters.

Figure 5.—Sample stability calculation.

the avalanche path you are interested in (fig. 5G). Compare the shear load with the sliding surface strength you calculated above. If they are within 10% of each other, you probably have an unstable slope. If the load is smaller than the true sliding surface strength (fig. 5H), subtract the load from the strength. The result is the additional load the sliding surface can withstand before fracturing. The new snow depth that the sliding layer can hold can be estimated by dividing the additional load by the new snow density times the sine of the slope angle (fig. 5I).

Equipment Needed

Almost any type of shovel will work, as long as it's strong enough for the shovel test. Similarly, the density kit used does not matter much. You will also need a device to measure slope angle. It only needs to be accurate to 1 or 2°.

The shear frame should be very similar to that shown in figure 1. A slight variation in shape is not too important, but the frame must have a base area of 250 cm². It also must have two reinforcing cross pieces.

The force gage *must* be calibrated in kilograms force (kgf). The range of possible forces that may be measured are 0.05–75 kgf. If the normal type of force gage is used, at least two gages, and probably three, will be required. The particular gage used must be heavy enough to measure the highest strengths in the layer and light enough so there is a good dial deflection for the lowest strengths. If the lowest readings give less than a 10% dial deflection, it is wise to use a lighter gage. A gage with a maximum deflection indicator is very helpful.

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